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(54) Title: CENTER OF GRAVITY CONTROL FOR HIERARCHICAL QAM TRANSMISSION SYSTEMS
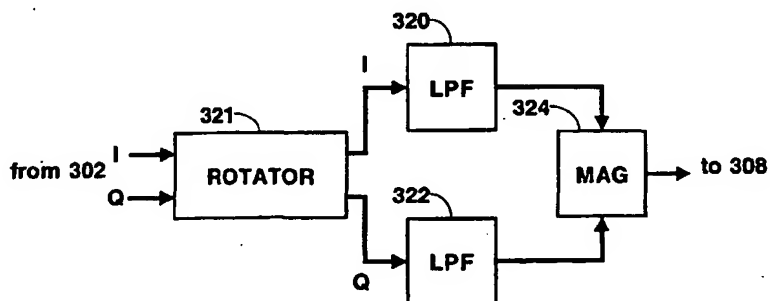
(57) Abstract: A QAM receiver calculates the location of the center-of-gravity of successive received data points in a quadrant. A level 1 decoder detects the quadrant in the I-Q plane of a received data point. Further circuitry translates the received data point in the I-Q plane such that the center-of-gravity of the detected quadrant is translated to the origin of the I-A plane. A level 2 decoder is then responsive to the translated data point for detecting the quadrant of the translated data point. A hierarchical QAM system allows the transmission of different sources by embedding the relative constellation points. In the hierarchical QAM receiver, a calculating circuitry determines the center of gravity of successive received data points in a quadrant. The displacement of the center of gravity is used in the decoding process when determining the single data streams pertaining to the different sources.

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CENTER OF GRAVITY CONTROL FOR HIERARCHICAL QAM TRANSMISSION SYSTEMS

FIELD OF THE INVENTION

The present invention relates to hierarchical quadrature amplitude

5   modulation transmission systems.

BACKGROUND OF THE INVENTION

Hierarchical quadrature amplitude modulation (QAM) transmission systems

are well known. For example, U.S. Patent 5,966,412, issued October 12, 1999

to Ramaswamy, discloses a modulation system which can remain backward

10   compatible with older quadrature phase shift keyed (QPSK) receivers, while

simultaneously further allowing additional data streams, for providing higher data

rates or higher precision data, to be receivable by more advanced receivers. Fig.

1 is a block diagram illustrating a hierarchical QAM transmission system as

disclosed in this patent. Fig. 1 discloses a data transmitter 100 coupled to a

15   data receiver 300 via a transmission channel 200.

In Fig. 1, a first input terminal DATA 1 is coupled to source (not shown) of

a first data signal, and a second input terminal DATA 2 is coupled to a source

(not shown) of a second data signal. The first and second data signals may

represent separate and independent data, or may represent related data signals,

20   such as signals carrying respective portions of the same data signal (for

increasing the throughput of the transmission system) or a elementary data

portion and a supplemental data portion of the same data signal (for transmitting

enhanced signals while maintaining backward compatibility with existing older

receivers, as described in more detail below). The first input terminal DATA 1 is

25   coupled to an input terminal of a first error detection/correction encoder 102.

An output terminal of the first encoder 102 is coupled to an input terminal of a

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level 1 QPSK modulator 104. An output terminal of the level 1 QPSK modulator 104 is coupled to a first input terminal of a signal combiner 106.

The second input terminal DATA 2 is coupled to an input terminal of a second error detection/correction encoder 108. An output terminal of the

5   second encoder 108 is coupled to an input terminal of a level 2 QPSK modulator 110. The level 2 QPSK modulator 110 is coupled to an input terminal of a variable gain amplifier 111, having a gain of G. An output terminal of the variable gain amplifier 111 is coupled to a second input terminal of the signal combiner 106. An output terminal of the signal combiner 106 produces a

10   combined modulated signal and is coupled to the transmission channel 200. In the illustrated embodiment, this channel is a direct satellite television signal transmission system, and the transmission channel includes a ground transmitting station at the transmitter 100 (represented by a transmitting antenna in phantom), a communications satellite (not shown), for receiving the

15   data from the ground station and rebroadcasting that data to a plurality of ground receiving stations, one of which (300) is illustrated in Fig. 1, which receives and processes the rebroadcast data signal, as illustrated by a receiving antenna in phantom.

The output of the transmission channel 200 is coupled to an input terminal

20   of a level 1 QPSK demodulator 302. An output terminal of the level 1 demodulator 302 is coupled to respective input terminals of a first error detection/correction decoder 304 and a delay circuit 306. An output terminal of the first decoder 304 is coupled to an output terminal DATA 1', and to an input terminal of a reencoder 308. An output terminal of the reencoder 308 is coupled

25   to an subtrahend input terminal of an subtractor 310. An output terminal of the delay circuit 306 is coupled to a minuend input terminal of the subtractor 310. A difference output terminal of the subtractor 310 is coupled to an input terminal

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of a second error detection/correction decoder 312. An output terminal of the second decoder 312 is coupled to a second data output terminal DATA 2'.

In operation, the first encoder 102 encodes the first data signal DATA 1 to provide error detection/correction capabilities in a known manner. Any of the

5   known error detection/correction codes may be implemented by the encoder/decoder pairs 102/304, 108/312, and those codes may be concatenated, as described in the above-mentioned patent. The first encoder 102 produces a stream of encoded bits representing the encoded first data signal DATA 1. The level 1 modulator 104 processes successive sets of two encoded

10   data bits, each set termed a symbol, to generate a QPSK signal which lies in one of four quadrants in a known manner. Similarly, the second encoder 108 encodes the second data signal DATA 2 to provide error detection/correction capabilities in a known manner. The level 2 modulator 110 processes sets of two encoded data bits to also generate a QPSK signal which lies in one of four

15   quadrants. One skilled in the art will understand that additional data signals (DATA 3, etc.) may be respectively error detection/correction encoded by additional encoders and additional QPSK modulators, (level 3, etc.) may be responsive to respective additional sets of two encoded data bits to generate additional QPSK signals. The QPSK signal from the level 1 modulator 104 is

20   given a weight of 1; the QPSK signal from the level 2 modulator 110 is given a weight or gain of .5 by the variable gain amplifier 111; the third a weight of .25 and so forth. All the weighted QPSK signals are then combined into a single modulated signal by the signal combiner 106 and transmitted through a transmission channel 200.

25   The level 1 QPSK modulator 104 causes the combined signal to lie within one of four quadrants in response to the set of two encoded data bits from the first encoder 102. Each quadrant, in turn, may be thought of as divided into four sub-quadrants. The level 2 QPSK modulator 110 causes the combined signal to

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lie within one of the sub-quadrants within the quadrant selected by the level 1 QPSK modulator 104, in response to the set of two input data bits from the second encoder 108. That sub-quadrant may further be though of as divided into four sub-sub-quadrants, and the combined signal caused to lie within one of

5   those sub-sub-quadrants in response to the set of two input data bits from a third encoder (not shown), and so forth.

An older receiver (illustrated in Fig. 1 by a dashed line 300') includes only a level 1 QPSK demodulator 302, which can detect where in the I-Q plane the received signal lies. From that information, the error detection/correction

10   decoder 304 can determine the corresponding two encoded bits in the received first data stream. The error detection/correction decoder 304 can further correct for any errors introduced by the transmission channel to generate a received data signal DATA 1' representing the original first data signal DATA 1. Thus, such a receiver can properly receive, decode, and process a first data signal DATA 1 in

15   the presence of additionally modulated data signals DATA 2, (DATA 3), etc. The signals included by the level 2 (and level 3, etc.) QPSK modulators look simply like noise to such a receiver.

A more advanced receiver 300, on the other hand, can detect which quadrant the received modulated signal lies within, and, thus, can receive,

20   decode, and process successive sets of two data bits representing the first data signal DATA 1. The reencoder 308 in the advanced receiver then regenerates an ideal signal lying in the middle of the indicated quadrant, which is subtracted from the received modulated signal. This operation translates the center of the transmitted signal quadrant to the origin. What remains is a QPSK modulated

25   signal, weighted by .5, representing the second data signal DATA 2. This signal is then decoded by the second decoder 312 to determine which sub-quadrant the signal lies within, indicating the set of two bits corresponding to that signal. Successive sets of two received data bits representing the second data signal

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DATA 2 are, thus, received, decoded and processed, and so forth. Such a transmission system operates by modulating a carrier in quadrature with what is seen as a constellation of permissible symbols, and is a form of quadrature amplitude modulation (QAM). Such a system is termed a hierarchical QAM

5   transmission system because it may be used to transmit other levels of data signals, or other levels of detail in a single signal, while maintaining backwards compatibility with older receivers.

Fig. 2a is a diagram illustrating a constellation in the I-Q plane of permissible symbols for a hierarchical 16QAM transmission system, as illustrated

10   in the above mentioned patent. In Fig. 2a, a first set of two bits determine which quadrant the generated symbol lies within. If the first two bits are "00" then the symbol lies within the upper right hand quadrant, and the level 1 modulator 104 produces I-Q signals such that $I = 1$ and $Q = 1$; if the first two bits are "01" then the symbol lies within the upper left hand quadrant, and the

15   level 1 modulator 104 produces I-Q signals such that $I = -1$ and $Q = 1$; if the first two bits are "10" then the symbol lies within the lower right hand quadrant and the level 1 modulator 104 produces I-Q signals such that $I = 1$ and $Q = -1$; and if the first two bits are "11" then the symbol lies within the lower left hand quadrant and the level 1 modulator 104 produces I-Q signals such that $I = -1$

20   and $Q = -1$. This is indicated in Fig. 2a by the appropriate bit pair in the middle of the associated quadrant.

As described above, each quadrant may, itself, be considered to be divided into four sub-quadrants, as illustrated in the upper right hand quadrant in Fig. 2a. The second set of two bits determine which sub-quadrant the symbol

25   lies within. The same mapping is used for determining the sub-quadrant as was described above for determining the quadrant. That is, if the second two bits are "00", then the symbol lies within the upper right hand sub-quadrant and the level 2 modulator generates an I-Q signal such that $I = 1$ and $Q = 1$; if the second

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two bits are "01" then the symbol lies within the upper left hand sub-quadrant

and the level 2 modulator generates an I-Q signal such that I = -1 and Q = 1; if

the second two bits are "10" then the symbol lies within the lower right hand

sub-quadrant and the level 2 modulator generates an I-Q signal such that I = 1

5   and Q = -1; and if the second two bits are "11" then the symbol lies within the

lower left hand sub-quadrant and the level 2 modulator generates an I-Q signal

such that I = -1 and Q = -1. The variable gain amplifier 111 (of Fig. 1) weights

the signal from the level 2 modulator 110 by a weight of .5, so the points in the

sub-quadrants lie at ±.5 around the center point of the quadrant. Each of these

10   locations is shown as a solid circle in Fig. 2a, with a four bit binary number

illustrating the combination of the first and second sets of two bits, with the first

two bits being the right hand pair of bits and the second two bits being the left

hand pair.

It is known that the bit error rate performance of the respective data

15   streams through the different levels of a hierarchical QAM system such as

described above are different. In general, the bit error rate of the level 1 data

stream is better than the bit error rate of the level 2 (and higher) data streams.

However, the overall performance of the hierarchical QAM transmission system

is optimized when the bit error rate of the respective data streams through the

20   different levels are the same. It is desirable, therefore, to optimize not only the

overall bit error rate of the transmission system, but also to more closely match

the respective bit error rates of the different levels in the transmission system.

SUMMARY OF THE INVENTION

The inventors have realized that when decoding a received signal, it is

25   imperative that the gain be controlled properly so that the values of the received

points in the constellation are in the proper range to be detected accurately.

However, due to the non-linearity inherent in a direct satellite television

transmission system, and to the practice of purposely distorting the location of

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the data points in the constellation to improve performance, the standard method of comparing the received constellation with an ideal constellation, and adjusting the gain to maximize the correspondence between the two will not result in optimum operation.

5   In accordance with principles of the present invention a QAM receiver includes a source of a received hierarchical QAM signal. The hierarchical QAM signal represents successive data points in the I-Q plane, each data point being in one of four quadrants. Circuitry, coupled to the hierarchical QAM signal source, calculates the location in the I-Q plane of the center-of-gravity of 10   successive received data points in a quadrant. A level 1 decoder is responsive to a received data point and detects the quadrant in the I-Q plane of a received data point. Further circuitry, coupled to the hierarchical QAM signal source and responsive to the calculating circuitry, translates the received data point in the I-Q plane such that the center-of-gravity of the detected quadrant is translated to 15   the origin of the I-Q plane. A level 2 decoder is then responsive to the translated data point for detecting the quadrant of the translated data point.

           Such a system can adapt to the received constellation, regardless of any distortion introduced into the constellation data points by non-linearities in the transmission channel, or purposely introduced into the transmitted constellation.

20   BRIEF DESCRIPTION OF THE DRAWING
           Fig. 1 is a block diagram of a transmission system in accordance with principles of the present invention;
           Fig. 2 is a diagram illustrating a constellation of permissible symbols for a hierarchical 16QAM transmission system;
25   Fig. 3a and c are more detailed block diagrams of respective portions of the transmission system illustrated in Fig. 1 and further including a gray code

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mapper, and Fig. 3b is a table containing data controlling the operation of the gray code mapper;

Fig. 4 is a more detailed block diagram of a portion of the transmission system illustrated in Fig. 1 illustrating the operation of differing error detection/correction codes for differing levels;

Fig. 5 is a diagram of a received constellation and Fig. 6 is a diagram of one quadrant of a received constellation distorted by the transmission channel;

Fig. 7 is a block diagram of circuitry for determining the center of gravity of a quadrant of a received constellation of data points; and

Fig. 8 is a diagram of a constellation illustrating the use of grouping factors to vary the relative bit rate performance of the different level signals in a hierarchical QAM signal.

DETAILED DESCRIPTION

Fig. 3a and c are more detailed block diagrams of respective portions of the transmission system illustrated in Fig. 1 and further including a gray code mapper, and Fig. 3b is a table illustrating the operation of the gray code mapper illustrated in Fig. 3a and c. Referring first to Fig. 2b, a constellation in which adjacent points at all locations represent data values which differ in only one bit position is illustrated. To produce this constellation, the mapping of the set of two bits in the encoded level 2 data signal to locations in a sub-quadrant depends on which quadrant that sub-quadrant lies within. The upper right hand quadrant (OO) in Fig. 2b is identical to that in Fig. 2a. In the upper left hand quadrant, however, the left and right columns are switched. In the lower right hand quadrant, the top and bottom rows are switched, and in the lower left hand quadrant, the left and right hand columns and the top and bottom rows are switched. This may be performed by a simple mapping operation in the transmitter 100 prior to modulating the encoded second data signal DATA 2, and then a simple demapping operation in the receiver 300 after the received encoded second data signal is demodulated.

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In Fig. 3a, a portion of the transmitter 100 is illustrated. A level 1 symbol (two bits from the first encoder 102 of Fig. 1) is coupled to respective input terminals of the level 1 modulator 104 and a gray code mapper 112. An in-phase (I) signal from the level 1 modulator 104 is coupled to a first input terminal

5 of a first adder 106(I) and a quadrature (Q) signal from the level 1 modulator 104 is coupled to a first input terminal of a second adder 106(Q). The combination of the first adder 106(I) and the second adder 106(Q) form the signal combiner 106 of Fig. 1. A level 2 symbol (two bits from the second encoder 108) is coupled to an input terminal of the level 2 modulator 110. An I output terminal

10 of the level 2 modulator 110 is coupled to an I input terminal of the gray code mapper 112, and a Q output terminal of the level 2 modulator 110 is coupled to a Q input terminal of the gray code mapper 112. An I output terminal of the gray mapper 112 is coupled to a second input terminal of the first adder 106(I) and a Q output terminal of the gray mapper 112 is coupled to a second input

15 terminal of the second adder 106(Q). The variable gain amplifier 111, conditioned to have an attenuation factor of .5 and coupled between the gray code mapper 112 and the signal combiner 106, is not shown to simplify the figure.

In operation, the level 1 symbol, represented by the set of two encoded

20 data bits, is received from the level 1 encoder 102 (of Fig. 1). The level 1 symbol is QPSK modulated by the level 1 modulator 104 to generate a set of I and Q component signals representing the quadrant of the modulated signal in a known manner. For example, if the symbol is 0, i.e. the two bits are 00, then the upper right hand quadrant is indicated (I = 1, Q = 1); if the symbol it 1, i.e.

25 the two bits are 01, then the upper left hand quadrant is indicated (I = -1, Q = 1); if the symbol is 2, i.e. the two bits are 10, then the lower right hand quadrant is indicated (I = 1, Q = -1); and if the symbol is 3, i.e. the two bits are 11, then the lower left hand quadrant is indicated (I = -1, Q = -1). In a similar manner, level 2 symbol is QPSK modulated by the level 2 modulator 110 to

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generate a set of I and Q component signals representing the sub-quadrant of

the modulated signal in a known manner. The level 2 modulator generates the

modulated signal in exactly the same manner as the level 1 modulator 104, i.e. if

the two bits are 00 (0), then the upper right hand sub-quadrant is indicated (I =

5   1, Q = 1); if the two bits are 01 (1), then the upper left hand sub-quadrant is

indicated (I = -1, Q = 1); if the two bits are 10 (2) then the lower right hand

sub-quadrant is indicated (I = -1, Q = 1); and if the two bits are 11 (3) then the

lower left hand sub-quadrant is indicated (I = -1, Q = -1). This modulated

signal is then weighted by .5 (not shown).

10   The resulting constellation from the combination of these two modulated

signals would be as illustrated in Fig. 2a. The gray code mapper 112 operates

on the I and Q signals from the level 2 modulator 110 to produce the

constellation illustrated in Fig. 2b. Fig. 3b illustrates the mapping applied by the

gray code mapper 112. If the level 1 symbol is 0, indicating the upper right

15   hand quadrant, then the sub quadrants are unchanged, that is the I and Q output

signals from the level 2 modulator are left unchanged. Thus, the I output signal,

Iout from the gray code mapper 112 is the same as the I input signal Iin (Iout =

Iin), and the Q output signal, Qout from the gray code mapper 112 is the same

as the Q input signal Qin (Qout = Qin). If, however the level 1 symbol is 1,

20   indicating the upper left hand quadrant, then, referring to Fig. 2, the columns are

switched. That is, positive I values become negative and *vice versa*. Thus when

the level 1 symbol is 1, the I output signal is the negative of the I input signal

(Iout = -Iin), while the Q output signal remains the same as the Q input signal

(Qout = Qin). If the level 1 symbol is 2, indicating the lower right hand

25   quadrant, then, the rows are switched. That is, positive Q values become

negative and *vice versa*. Thus, when the level 1 symbol is 2, the I output signal

is the same as the I input signal (Iout = Iin), while the Q output signal is the

negative of the Q input signal (Qout = -Qin). If the level 1 signal is 3, indicating

the lower left hand quadrant, then, both the columns and the rows are switched.

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That is, positive I values become negative , and positive Q values become negative, and *vice versa*. Thus, when the level 1 symbol is 3, the I output signal is the negative of the I input signal (Iout = -Iin), and the Q output signal is the negative of the Q input signal (Qout = -Qin). The gray code mapper 112

5   provides this function. The resulting I and Q values from the gray code mapper 112 are weighted with a weight of .5 as described above (not shown for simplicity) and combined by the signal combiner 106 with the I and Q values representing the level 1 symbol. The resulting constellation is that illustrated in Fig. 2b.

10   Such a mapping is reversible in the receiver 300 using a similar gray code mapper. Fig. 3c illustrates a portion of a receiver 300 including such a gray code mapper 314. In Fig. 3c, the output terminal of the reencoder 308 is coupled to an input terminal of the gray code mapper 314. An I signal from the subtractor 310 (of Fig. 1) is coupled to an I input terminal of the gray code mapper 314 and

15   a Q signal from the subtractor 310 is coupled to a Q input terminal of the gray mapper 314. An I output terminal of the gray code mapper 314 is coupled to an I input terminal of the second decoder 312 and a Q output terminal of the gray code mapper 314 is coupled to a Q input terminal of the second decoder 312.

              In operation, the reencoder 308 generates a signal which is an ideal

20   representation of the received level 1 symbol. That is, if the received level 1 signal is determined to lie anywhere in the upper right hand quadrant, then the reencoder 308 produces a signal having the value 0; if anywhere in the upper left hand quadrant a value 1, if anywhere in the lower right hand quadrant a value 2 and if anywhere in the lower left hand quadrant a value 3. This symbol

25   is supplied to a gray code mapper 314. Respective I and Q signals from the subtractor 310 are processed by the gray code mapper 314 in the manner described above, and illustrated in Fig. 3b. One skilled in the art will appreciate that the gray code mapper 314 in the receiver 300 operates identically to the

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gray code mapper 112 in Fig. 3a, and will perform the inverse function
performed in the transmitter 100.

The use of gray code mappers (112 and 312) in the transmitter 100 and
receiver 300 allow use of a constellation as illustrated in Fig. 2b, in the manner
described above with respect to Fig. 3a. A transmission system using the gray
code mapping function described above, to produce a constellation in which
adjoining constellation points differ by no more than a single bit will increase the
bit error rate of the system. Simulations have shown that using gray coding as
described above will cut the number of level 2 bit errors in half. This provides an
extra margin in the signal to noise ratio (SNR) of around ¼ dB. This
improvement, while modest, will, along with other enhancements, provide
improved performance of the transmission system as a whole.

Fig. 4 is a more detailed block diagram of a portion of the transmission
system illustrated in Fig. 1 illustrating the operation of differing error
detection/correction codes for differing levels. As described above, different
levels of QPSK modulation suffer from differing levels of degradation due to the
compression of the distance between the constellation points in the higher levels
of modulation by the non-linear high powered amplifiers employed in satellite
broadcasting. More specifically, bit errors inherently occur more often at higher
levels of the hierarchical modulation than lower levels. To more closely match
the bit error rates of the level 1 and level 2 signals, error detection/correction
codes having differing performance characteristics are used in the respective
data streams. More specifically, more powerful error detection/correction coding
will be used in higher level data streams while less powerful error
detection/correction coding will be used on lower level data streams. This will
optimize the overall performance and information transmission capacity of the
transmission system.

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In Fig. 4, those elements which are the same as those illustrated in Fig. 1 are designated with the same reference number and are not described in detail below. In Fig. 4, the first error detection/correction encoder 102 in the transmitter 100 is partitioned into a serial connection of an outer encoder 102(O)

5   and an inner encoder 102(I). Similarly, the second error detection/correction encoder 108 is partitioned into a serial connection of an outer encoder 108(O) and an inner encoder 108(I). In a corresponding manner, the first error detection/correction decoder 304 in the receiver 300 is partitioned into a serial connection of an inner decoder 304(I) and an outer decoder 304(O). Similarly,

10 the second error detection/correction decoder 312 is partitioned into a serial connection of an inner decoder 312(I) and an inner encoder 312(O). As disclosed in the above mentioned patent, the outer encoder/decoder pairs implement a block coding technique, such as Hamming codes, Hadamard codes, Cyclic codes and Reed-Solomon (RS) codes, while the inner encoder/decoder

15 pairs implement a convolutional code.

In Fig. 4, the coding used for the level 2 data stream is more powerful than the coding used for the level 1 data stream. More specifically, the convolutional code used in the inner encoder/decoder pair in the level 2 data stream is more powerful than the convolutional code used in the inner

20 encoder/decoder pair in the level 1 data stream. For example, in a preferred embodiment, the first inner encoder/decoder pair, processing the level 1 data stream, implements a rate ½, constraint length 7 convolutional code punctured to a rate of ▯. The second inner encoder/decoder pair, processing the level 2 data stream, implements a rate ½ convolutional code without puncturing. The

25 coding of the level 2 data stream is more powerful than that of the level 1 data stream. This more closely matches the bit error rate performance of the level 1 and level 2 data streams, and optimizes the performance of the transmission system as a whole.

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As described above, and illustrated in Fig. 1, the level 1 demodulator 302 and decoder 304 cooperate to detect the DATA 1 signal from the received constellation. Then a reconstructed ideal signal, from reencoder 308, representing this detected DATA 1 signal is then subtracted from the received

5   constellation, and ideally results in translation of the received constellation to form another constellation of the sub-quadrants within the detected quadrant. However, this translation operation is very sensitive to any mismatch between the actual "center point" of the quadrant as received, and the ideal center point (displaced by ± 1 from the origin of the level 1 constellation) assumed by the

10   reencoder 308. Any mismatch in size between the received constellation and the ideal constellation results in the actual center point of the received quadrant being displaced from the assumed center point, and when the received constellation is translated by the reencoder 308 and subtractor 310, results in the actual center point of the displaced sub-quadrant being displaced from the

15   origin assumed by the second decoder 312. Thus, the gain of the received channel must be accurately adapted to, in order to place the center point of the sub-quadrant in the proper location (origin) to be accurately decoded by the second decoder 312.

In known transmission systems, the gain of the system is determined by

20   comparing the received constellation of data points to a known ideal constellation of data points. There are several problems associated with accurate maintenance of the gain in this manner, however. First, in some transmission systems, the locations of the constellation points may be deliberately distorted from their ideal locations. The resulting constellation does

25   not have the equi-spaced points illustrated in Fig. 2. Second, the transmission channel is not constant, and may be noisy with varying amounts of non-linearity. To determine the location of the center point of the quadrants, and thus the gain of the system, in such systems, the center-of-gravity of all the data points in the quadrants is determined.

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Fig. 7 is a block diagram of circuitry for determining the center of gravity
of a quadrant of a received constellation of data points. In Fig. 7, a rotator 321
receives I and Q values representing I and Q components of successive received
data points from the level 1 demodulator 302 (of Fig. 1). An I output terminal of

5   the rotator 321 is coupled to an input terminal of an I low pass filter (LPF) 320.
A Q output terminal of the rotator 321 is coupled to an input terminal of a Q LPF
322. Respective output terminals of the I and Q LPFs, 320 and 322, are
coupled to corresponding input terminals of a magnitude calculating circuit 324.
An output terminal of the magnitude calculating circuit 324 is coupled to the

10   reencoder 308.

In operation, the rotator 321 rotates all of the received values from
whatever quadrant they were received in to the upper right hand quadrant in a
known manner. Fig. 5 is a diagram of a received constellation and shows the
locations of a plurality of successive received modulated data points. The

15   received data points form scatters in the respective neighborhoods of the
assumed locations of the received constellation points in all four quadrants. Fig.
6 is a diagram of the upper right hand quadrant of a received constellation all of
whose data points have been rotated to this quadrant by the rotator 321. The
quadrant illustrated in Fig. 6 represents a constellation which has been distorted

20   by either deliberate pre-distortion of the transmitted constellation points and/or
by the operation of the transmission channel 200.

The I component of the rotated data points from the rotator 321 is low
pass filtered in the LPF 320 with a sliding moving average of n points. In the
illustrated embodiment, the sliding moving average is calculated using the

25   preceding 500 data points. The Q component of the rotated data points from
the rotator 321 is similarly low pass filtered with a sliding moving average. One
skilled in the art will understand that the low pass filters 320, 322 may also be
constructed using respective IIR digital filters. The low pass filtering operation

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produces the respective I and Q components of the center of gravity of the
received data points in the quadrant. The estimate of the magnitude of the
center of gravity is calculated in the magnitude calculating circuit 324. For
example if $r_i[n]$ is the filtered in-phase I component, and $r_q[n]$ is the filtered

5   quadrature Q component, then the magnitude of the center of gravity is

calculated as $M = \sqrt{r_i[n]^2 + r_q[n]^2}$. The magnitude of the center of gravity M

should ideally be $\sqrt{2} = 1.4$. The magnitude of the ideal reconstructed signal
from the reencoder 308 is adjusted in response to the magnitude of the
calculated center of gravity M. By properly adjusting the magnitude of the

10   reconstructed ideal signal from the reencoder 308, the centers of the respective
received quadrants will be properly translated to the origin by the subtractor
310, and allow for accurate decoding of the level 2 and higher data signals.

    The circuit illustrated in Fig. 7 will operate independently of the method of
transmission, whether linear or non-linear. It also operates properly in the

15   presence of a pre-distorted transmission constellation, or with non-standard
grouping factors (described in more detail below). It has been found that the
circuit works well in practice with no measurable degradation when used on
hierarchical 16QAM transmission system over a linear channel when compared
with exact knowledge of the locations of the centers of the quadrants. The

20   circuit also operates well in the presence of noise and in particular in the
presence of channel distortion caused by non-linear channels, such as found in
direct satellite television signal transmission systems. Such a circuit improves
the performance of the higher level data streams, and thus, improves the overall
performance of the transmission system.

25   Referring again to Fig. 1, in known hierarchical QAM transmission
systems, the constellation generated by the level 2 modulator 110 is combined
in the signal combiner 106 with the constellation generated by the level 1
modulator 104 after being weighted in the variable gain amplifier 111 by a factor

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of .5.   The weighting factor of .5 is termed the grouping factor and may be varied to change the relative performance of the level 1 and level 2 data streams, as described in more detail below. Referring to Fig. 2a, the resulting constellation consists of equi-spaced constellation points. As described above,

5   such an arrangement results in a transmission system in which the performance of the level 1 data stream, in terms of bit error rate, is better than that of the level 2 data stream. By varying the grouping factor, the relative performance of the level 1 and level 2 data streams may be more closely matches.

Referring to Fig. 8a, the gain of the variable gain amplifier (111 of Fig. 1)

10   is conditioned to be .3. The resulting constellation points are spaced only .3 from the center point of the quadrant. One skilled in the art will recognize that in the constellation illustrated in Fig. 8a, the constellation points in a quadrant are further away from constellation points in other quadrants than in the constellation illustrated in Fig. 2a. Conversely, the constellation points within a

15   quadrant are closer together than those illustrated in Fig. 2a. Such a system allows more accurate determination of which quadrant the level 1 data signal is in at the expense of less accurate determination of the constellation point of the level 2 data signal within the quadrant, thus, increasing the performance of the level 1 data stream and decreasing the performance of the level 2 data stream,

20   when compared to the system of Fig. 2a.

Referring to Fig. 8b, the gain of the variable gain amplifier (111 of Fig. 1) is conditioned to be .7. The resulting constellation points are spaced .7 from the center point of the quadrant. One skilled in the art will recognize that in the constellation illustrated in Fig. 8b, the constellation points in a quadrant are

25   closer to constellation points in other quadrants than in the constellation illustrated in Fig. 2a. Conversely, the constellation points within a quadrant are further apart than those illustrated in Fig. 2a. Such a system allows more accurate determination of the constellation point of the level 2 data signal within

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the quadrant at the expense of less accurate determination of which quadrant the level 1 data signal is in, thus, increasing the performance of the level 2 data stream and decreasing the performance of the level 1 data stream, when compared to the system of Fig. 2a.

5   By proper setting of the gain of the variable gain amplifier 111 (of Fig. 1), the grouping of the constellation points with each cluster may be placed optimally to more closely match the performance of the level 1 and level 2 data streams. It has been determined that for a 16QAM transmission system transmitted through a non-linear direct satellite television channel, a grouping
10   factor of around .6 to around .7 will more closely match the bit error rate performance of the level 1 and level 2 data streams. This will increase the overall performance of the transmission system as a whole.

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CLAIMS

1.   A QAM receiver, comprising:

an input for receiving a hierarchical QAM signal, representing successive data points in the I-Q plane, each data point being in one of four quadrants;

5   circuitry, coupled to the hierarchical QAM signal input, for calculating the location in the I-Q plane of the center-of-gravity of successive received data points in a quadrant;

a level 1 decoder, responsive to a received data point, for detecting the quadrant in the I-Q plane of a received data point;

10   circuitry, coupled to the hierarchical QAM signal input and responsive to the calculating circuitry, for translating the received data point in the I-Q plane such that the center-of-gravity of the detected quadrant is translated to the origin of the I-Q plane; and

a level 2 decoder, responsive to the translated data point for detecting the

15   quadrant of the translated data point.

2.   The receiver of claim 1 wherein:

the hierarchical QAM signal input receives signals representing respective I and Q components of the successive data points in the I-Q plane; and

the calculating circuitry comprises:

20   a first low pass filter, responsive to the I component, for calculating the I component of the center-of-gravity of the successive received data points in quadrant of the I-Q plane;

a second low pass filter, responsive to the Q component, for calculating the Q component of the center-of-gravity of the

25   successive received data points in the quadrant of the I-Q plane; and

a magnitude calculating circuit, coupled to the first and

20

second low pass filters, for calculating the magnitude of the center-of-gravity of the quadrant of the I-Q plane; wherein:

the translating circuitry translates the received data point by a distance equal to the calculated magnitude.

5   3.   The receiver of claim 2 wherein the first and second low pass filters are IIR filters.

4.   The receiver of claim 2 wherein the first and second low pass filters comprise circuitry for calculating a sliding moving average.

5.   The receiver of claim 4 wherein the magnitude calculating circuit

10   calculates the magnitude $M = \sqrt{r_i[n]^2 + r_q[n]^2}$, wherein $r_i[n]$ represents the sliding moving average of the I component over n points, and $r_q[n]$ represents the sliding moving average of the Q component over n points.

6.   The receiver of claim 4 wherein the sliding moving average is calculated over 500 points.

15   7.   The receiver of claim 1 further comprising a rotator, coupled between the hierarchical QAM signal input and the calculating circuitry, for rotating the quadrant of each of the successive received data points to a single predetermined quadrant; wherein

the calculating circuitry calculates the location of the center-of-gravity of

20   successive rotated received data points in the predetermined quadrant in the I-Q plane.

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8.   The receiver of claim 1 wherein the hierarchical QAM signal source comprises a satellite receiving antenna, adapted to receive a satellite signal carrying the hierarchical QAM signal.

9.   In a QAM receiver, a signal processing method comprising the steps

5   of:

receiving a hierarchical QAM signal representing successive data points in the I-Q plane, each point being in one of four quadrants;

calculating the location in the I-Q plane of the center-of-gravity of successive received data points in a quadrant;

10   detecting, at a first level, the quadrant in the I-Q plane of a received data point;

translating, in response to the calculating step, the received data point in the I-Q plane such that the center-of-gravity of the detected quadrant to the origin of the I-Q plane; and

15   detecting, at a second level, the quadrant of the translated data point.
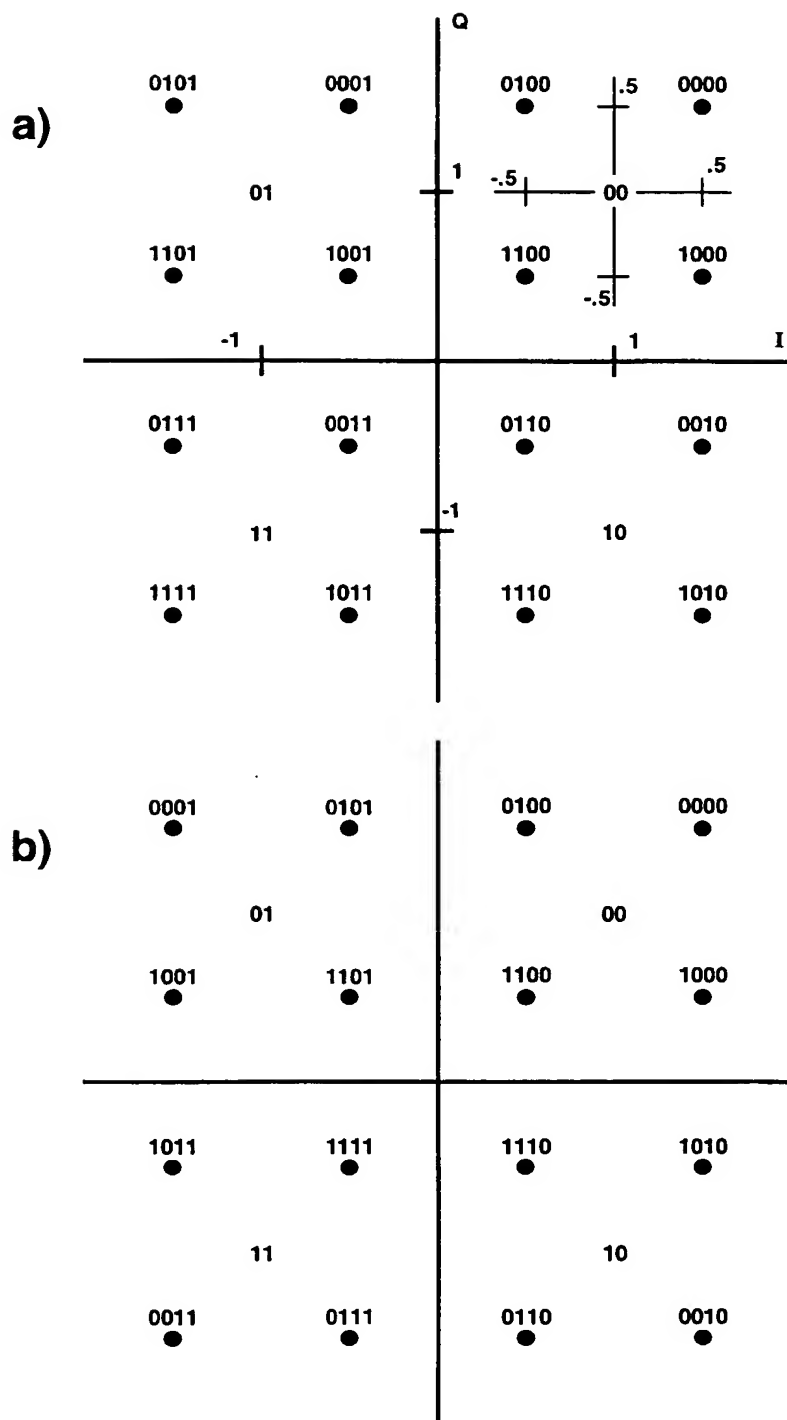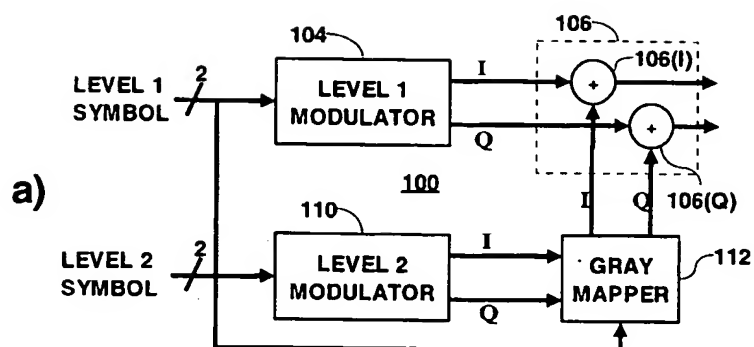
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Fig. 1

Fig. 2

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a)
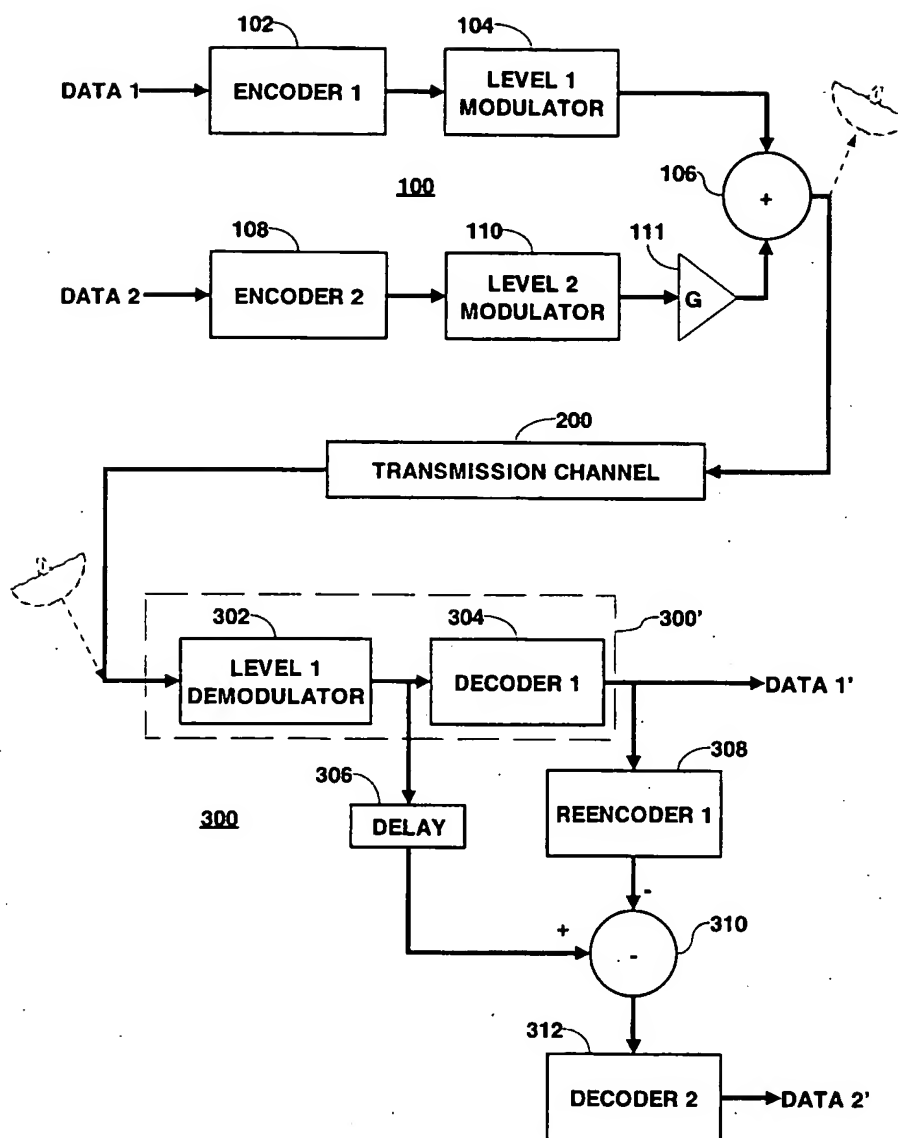
b)

Level 1 Symbol	Level 2 Iout	Level 2 Qout
0	Iin	Qin
1	-Iin	Qin
2	Iin	-Qin
3	-Iin	-Qin

•

c)

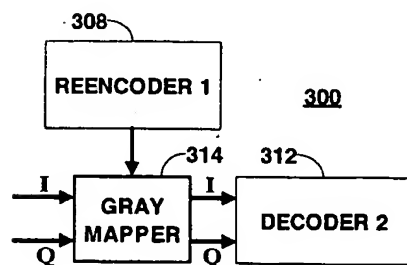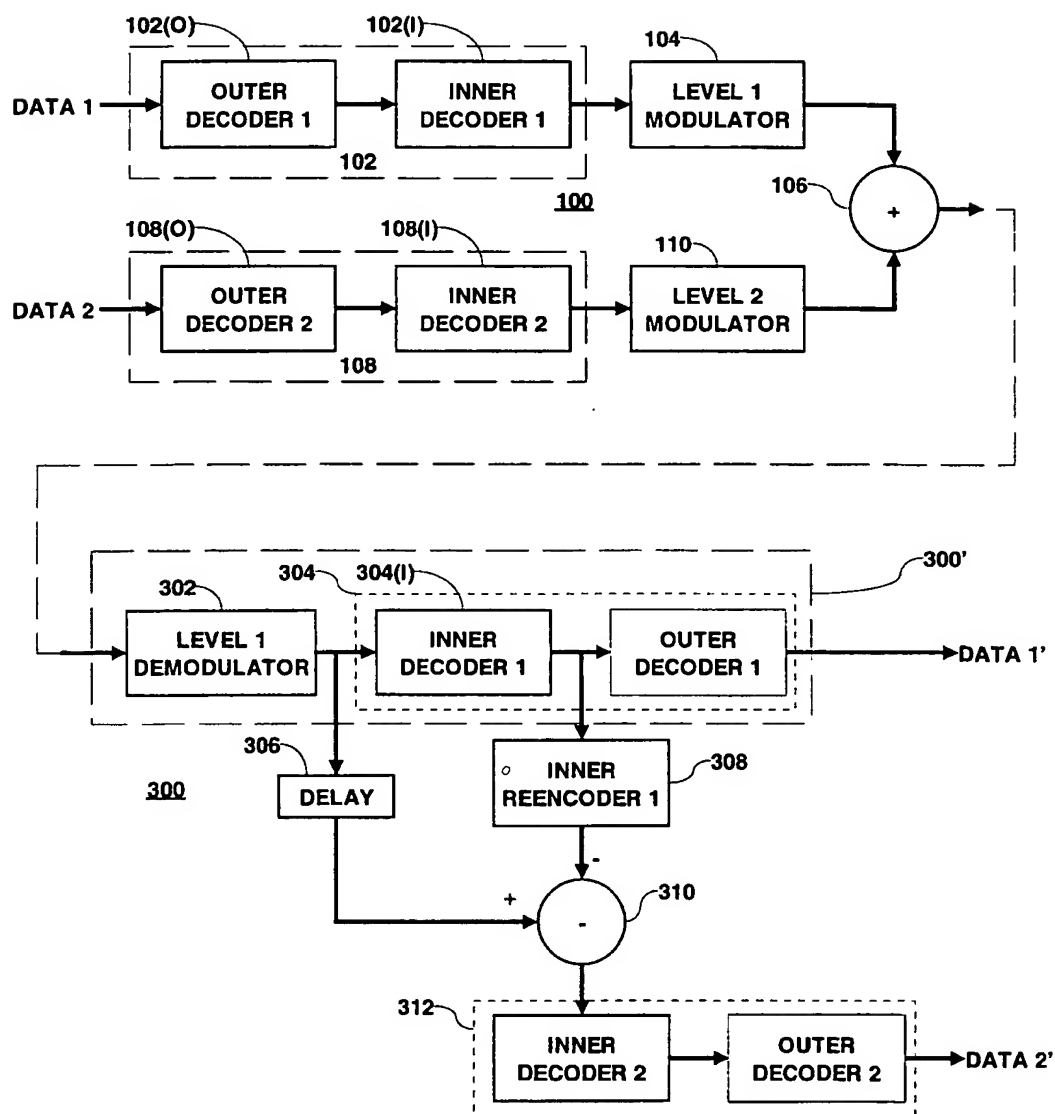Fig. 3

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Fig. 4
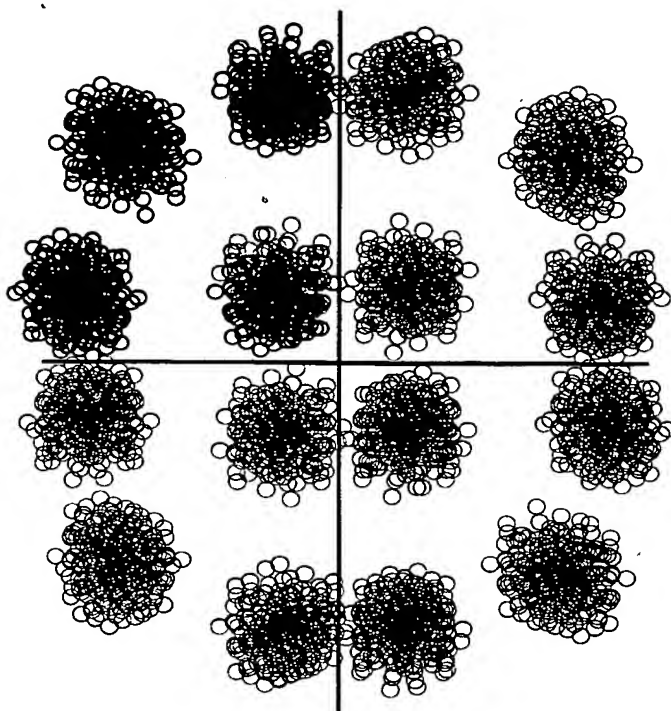
Fig. 5
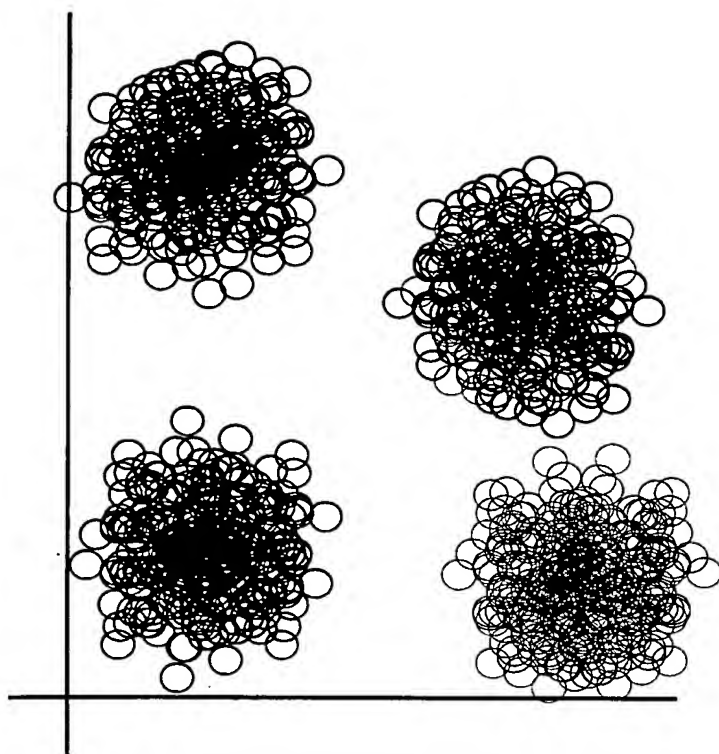
Fig. 6
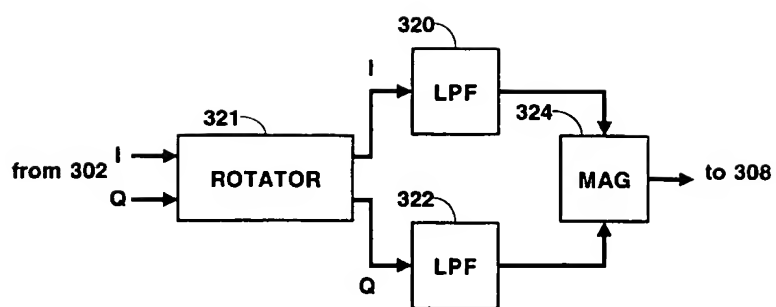
Fig. 7

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Fig. 8

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7   H04L27/34

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7   H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, INSPEC, COMPENDEX

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 594 505 A (TELEDIFFUSION FSE ;FRANCE TELECOM (FR)) 27 April 1994 (1994-04-27) column 8, line 22 - line 53 column 11, line 15 - line 23 column 17, line 55 -column 18, line 2	1,7-9
Y	figures 3B,3E	2
Y	EP 0 366 159 A (HEWLETT PACKARD LTD) 2 May 1990 (1990-05-02) page 9, line 49 -page 10, line 1 figure 9	2

☐ Further documents are listed in the continuation of box C.   ☒ Patent family members are listed in annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
26 February 2001	09/03/2001

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Farese, L

Form PCT/ISA/210 (second sheet) (July 1992)

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